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Full Length Research Paper

A study of the amounts of fertilizers for optimum yields of wheat grown under residual soil moisture condition and the returns associated with production

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Wheat production in winter under wetland conditions has been low due to lack of topdressing because very little or no rains fall in winter. Due to water logging in summer nutrients are leached remaining with very little to sustain the winter crops. This paper examines the effects of two different types of compounds (Cmp) and ammonium nitrate (AN) applied at different rates as basal dressing under residual moisture conditions. Treatments tested were zero (control); Basal 250 kg/ha Cmp. D (7N:14P:8K); Basal (250 kg/ha Cmp D + 52.5 kg/ha N); Basal (500 kg/ha D + 105 kg/ha N); Basal 350 kg/ha Cmp X(20N:10P:5K); Basal 700 kg/ha Cmp X; Basal (500 kg/ha Cmp. D+ 35 kg/ha N; Basal 500 kg/ha); and Basal 140 kg/ha N as AN(34.5%N). Results showed that zero fertility and applying 250 kg/ha D with 52.5 kg/ha N at planting took significantly shorter number of days to flower in both seasons. Zero fertility and applying 250 kg/ha D with 52.5 kg/ha N at planting had significantly lighter seed weight in both seasons. Significant yield differences existed among treatments with zero fertility, 250 kg/ha D, and 250 kg/ha D with 52.5 Kg/ha N and 140 kg/ha N at planting showing significantly lower yields as compared to applying 500 kg/ha D with 105.5 kg/ha N and 500 kg/ha D with 35.5 kg/ha N at planting in both seasons. There were no significant yield differences in applying compound X at 700, 350 and 500 kg/ha D with 35 kg/ha N at planting in both seasons. There were no significant yield differences between 500 kg/ha D, 140 kg/ha N, 250 kg/ha D +52.5N and 250 kg/ha D in the first season. Positive gross margin were realised when 350kg/ha Compound X was applied in both seasons. Applying 140kg/ha N at planting had least positive gross margin in both seasons.

Key words: Residual soil moisture, ammonium nitrate, compound, yield, gross margins.

INTRODUCTION

Wheat is a widely adapted crop because it is grown from temperate, irrigated to dry and high-rain-fall areas and from warm, humid to dry, cold environments (Acevedo et al., 1998). Wide adaptation has been possible due to the complex nature of the plant's genome, which provides great plasticity to the crop. Wheat is a C3 plant and as such it thrives in cool environments. In Zimbabwe wheat is grown in winter under irrigation conditions. However, some farmers grow wheat under wetland conditions (residual moisture) in some parts of the country because

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little or no rains are received in winter. Under these conditions the crop survives on residual moisture throughout the cropping season (Mugabe and Nyakatawa, 2000). Yields ranging from 1 up to 3 t/ha have been obtained under such conditions depending on the quality of the preceding rain season (Mugabe and Nyakatawa, 2000). Crop responses to NPK-fertilization depend on the level of water availability (Pala et al., 1996). On average, the application of 5, 10 and 15 g N m^2 significantly increased water use efficiency for grain yield of wheat from <6.0 kg ha^1 mm^1 to between 8.0 and 9.9 kg ha^1 mm^1 (Oweis et al. 2000). Both Cmps and nitrates are required for wheat production. Placement of phosphate fertilizer and availability of micronutrients like copper, boron and zinc were shown to be critical especially when high yields are targeted (Zeidan, 2010; Tanner and Cooper, 1984). At Chiredzi Research Station (429 m above sea level) Cmp X (20N:10P:5K) was recommended at a rate of 700 kg/ha as basal without topdressing (Wilson 1978). Cmp X can also be used in wetlands for wheat production as an alternative of using Cmp D (7N:14P:8K). Cmp D is used with topdressing because its N content is too low to attain optimum yields. However, soil moisture levels might affect top dressing at the time it is required, because there will be no rains or irrigation to dissolve it under residual moisture conditions. Under such cases Cmp X would be ideal. The amount of Cmp X recommended may be too high under these conditions given the low levels of expected yields and limited residual moisture. If farmers do not apply Cmp D, the feasibility of applying 140kgN/ha at planting as Ammonium nitrate (34.5%N) needs to be evaluated as well and compared to the use of Cmp X at recommended rates and half application rates. Therefore the objective of the study was to find the type and optimum amounts of fertilizers for optimum yields of wheat grown under residual soil moisture condition and to assess the returns associated with production.

MATERIALS AND METHODS

Study site and crop establishment

A trial was conducted under wetland conditions at Zungwi vlei (20° 25` S and 30° 25` E) in Zvishavane District Natural Region IV of Zimbabwe on two wetlands located about 1 km apart. The sites comprised of two cultivation systems namely Broad Ridge and Broad Furrow (BR/BF) or Ngwarati system (Mharapara, 2000) and Dead end level contour (DELC) systems. The BR/BF system consists of broad ridges and furrows that are developed on contour. They are developed in an alternating sequence starting from the highest point of the vlei. The furrows are designed in a feeder system (Mharapara, 2000) where the first furrow is filled up to a pre-determined level of 30 cm and feed the next lower furrow. The first ridge, which is called the master ridge, holds and stabilises water flowing from the catchments. Both the broad furrows and broad ridges are 2 to 4 m wide and the ridges are 60 cm high so that they can hold the water to a level of 30 cm high in the above furrow. The furrows from the top to the last bottom are all filled with water, which finally collects into the fish-pond. The BR/BF system is developed by a cut and fills method where soil from the furrow is used to build the ridge. The topsoil from the furrow forms the base of the ridge and the sub-soil forms the top of the ridge. Water movement from the catchments usually brings litter and manure and improve the furrow soil texture (Mharapara, 2000). The wheat crop was grown on the ridge top and utilized water from the furrow through capillary movement.

The DELC system is composed of the rectangular trench 0.75 to 1 m deep by about 1 m wide dug along the contour. Excavated soil was placed at the lower side of the trench, the opposite of the *fanya juu*. The next trench followed on the next contour line being about 30 m apart. The block in-between was planted with wheat. Water collected by the trench moved down slope supplying moisture to the crops. The dead end level contour was taken as a control because this system was used by local farmers as their water conservation farming method. This method did not have a self feeding mechanism like the BR/BF as far as above ground water flow was concerned. However, there was communication through underground movement. The contour released water to the lower field and subsequent contour below benefit crops.

Soil samples were collected from experimental sites 0 to 45 cm using a bucket auger at random both on BR/BF system and DELC system before and after the trial from pre-marked plots. Samples taken were put in paper pockets, air dried and sieved and sent to Zimbabwe Sugar Association Experiment Station (ZSAES) for analysis. Soil texture was determined by the fore finger and thumb method and use of the soil classification chart. Organic matter content was determined using the sulphuric acid-potassium dichromate method. Soil pH was done with 1:5 Suspensions (soil: $CaCl_2$). Clay, sand and silt were determined using the sedimentation method by soil hydrometer. Mineral nitrogen was done using 0.01m KCL extract done by titrimetry. Phosphate analysis was done using the Resin extract on UV-Vis spectroscopy. Potash, calcium, magnesium and sodium were done by Atomic Absoption Spectroscopy. Rainfall data was also recorded using plastic rain gauges.

Planting lines were then made and basal fertilizers applied per planting rows at the same time in May for the two sites. The crop was planted on the 5^{th} of May for both seasons and sites. Row spacing was 25 cm and sowing at a rate of 100 kg/ha. Two middle rows with two plants discarded on either side were harvested for yield measurements. The yield components measured was thousand seed weight (g). Other parameters measured were grain yield (g/plant) and moisture content.

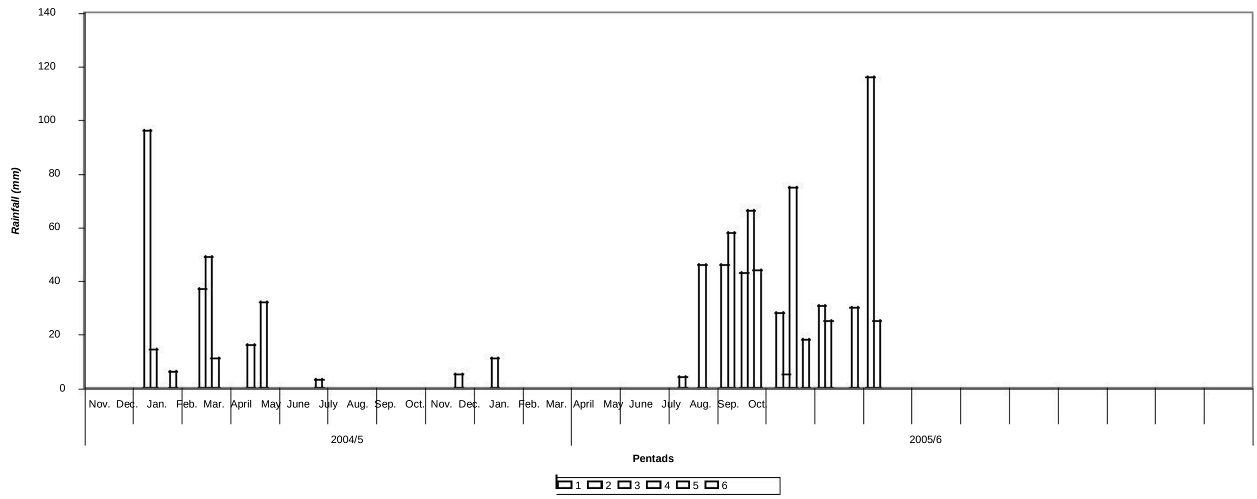

Figure 1. Rainfall over the two seasons in Zungwi vlei.

Total grain weight (Kg per hectare) was calculated using net plot grain weight and adjusted to 12.5% grain moisture recommended by Grain Marketing Board. Grain moisture content at harvesting was determined by use of a moisture meter.

Experimental procedure and treatment

The effects of 9 fertilizer combinations were evaluated. A wheat variety Nduna was used in the experiment. The trial was set up in a randomized complete block design with nine treatments. Each treatment factor was replicated three times. Compound D (7N:14P:8K), Compound X (20N:10P:5K and Ammonium nitrate (34.5%N) are fertilizers produced by Windmill Zimbabwe Company Pvt (Ltd).Treatments were as follows:

1. 0 kg/ha (Control)
2. 250 kg/ha Cmp D basal
3. 250 kg/ha Cmp D basal + 52.5 kg/ha N at planting.
4. 500 kg/ha Cmp D basal + 105 kg/ha N at planting
5. 350 kg/ha Cmp X basal
6. 700 kg/ha Cmp X basal
7. 500 kg/ha Cmp D basal + 35 kg/ha N at planting
8. 140 kg/ha N at planting. (As Ammonium nitrate)
9. 500 kg/ha Cmp D basal

Statistical analysis

Data was subjected to analysis of variance procedure as randomised complete block design using Genstat. The data was adjusted to 12.5% moisture content before analysis. Least significant differences were used to separate means at $p<0.05$ where necessary using Mstatc. An economic analysis was also conducted to determine whether it was economically viable to apply fertilizers at the rates studied.

The following costs were considered in the economic analysis. The number of labour days used was twenty-seven per hectare recommended in the production handbook at US$2.00 per day, cost of seed was calculated at US$35.00 per 25 kg bag applied at 100 kg/ha and fertilizers were calculated at US$32.00 per 50 kg bag of Cmp D and Cmp X at $35.00 per 50 kg bag. Ammonium Nitrate was calculated at $33 per bag. The selling price of wheat was US$400.00/t GMB price.

Rainfall data for the two rain seasons

Monthly rainfall distribution for Zungwi from December to October for the two seasons 2004/5 to 2005/6 is presented (Figure 1). The rainfall started in the second pentad of December and ended in the second pentad of March giving three months of growing season in 2004/5 and started during the fifth pentad of November and ended during the second pentad of March (3.5 months) for 2005/6 season.

RESULTS

Total rainfall for DELC and BR/BF were 307 and 309.5 mm for 2004/2005 season and 638 and 639 mm for 2005/2006 season respectively. The first season was characterised by low, erratic and poorly distributed rainfall, whilst the second season had better rainfall distribution (Figure 1) but with very heavy rainstorms that gave 116 mm in 5 days. Distribution was highly skewed in both years with 42% of the annual total rainfall received in December in the first season and 40% in the same month in the second season. Both sites received 31 and 20%

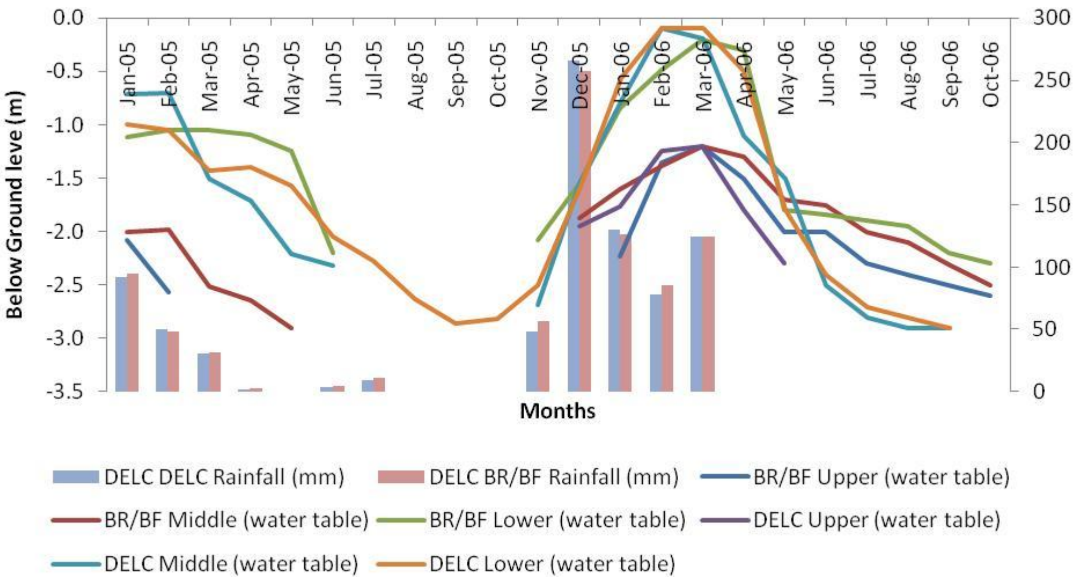

Figure 2. Monthly piezometer readings at Zungwi BR/BF and DELC system as influenced by rainfall in 2004/5 and 2005/ seasons

Table 1. Soil texture, organic matter, soil pH and mineral content for BR/BF and DELC system.

Site	% Clay	% Silt	% Sand	OM %	pH (1:5 suspension Soil:$CaCl_2$)	Mineral N ppm After Incubation	P_2O_5 (ppm)	Extractable cations (m.e %)			
								K	Ca	Mg	Na
BR/BF system	8[a]	2.88[b]	89.1[a]	0.22[a]	4.37[b]	18.24[a]	32.1[a]	0.107[a]	0.92[a]	0.2[b]	0.05[c]
BR/BF system	8[a]	2.25[b]	89.6[a]	0.25[a]	3.91[c]	27.13[a]	23.6[ab]	0.13[a]	0.48[b]	0.13[b]	0.06[bc]
BR/BF system	8[a]	1.63[b]	90.3[a]	0.28[a]	4.21[b]	19.75[a]	21.8[b]	0.11[a]	0.53[b]	0.21[b]	0.11[ab]
DELC system	4.5[b]	13.1[a]	82.3[b]	0.30[a]	4.70[a]	16.63[a]	7.2[c]	0.06[a]	0.76[a]	0.6[a]	0.12[a]
Mean	7.1	4.95	87.8	0.26	4.296	20.43	21.2	0.10	0.67	0.28	0.08
LSD at 5%	0.52	2.3	2.33	0.09	0.285	17.3	9.63	0.09	0.21	0.156	0.045
S.E	0.18	0.81	0.82	0.034	0.1	6.075	3.38	0.03	0.07	0.054	0.016
CV%	5.12	32.6	1.86	25.4	4.65	59.5	31.9	60.5	21.8	37.8	39.2

in January first and second season respectively. Rainfall was below average in 2004/2005 season and above average in 2005/2006 season. However there were no significant rainfall amount differences between the DELC and BR/BF schemes in both seasons. Significant differences occurred between seasons. The previous rainfall season had a bearing on the quality of the winter season for the growth of wheat.

Water table and soil moisture content

When water table measurements were taken in January 2005 levels showed that water levels were high (Figure 2). Rains had started in December 2004, and influenced rise in underground water levels in all the points except the upper section of the DELC system. Water table levels decreased up to June when all the access tubes dried except the lower section of the DELC which never dried up until the next rains that came in November 2005. The second season saw all points rising in water levels up to almost ground levels in February 2006. This water table had a great influence in wheat production in winter 2006. The BR/BF in May 2005 water table was 2.5 to 3 m below ground level whilst in 2006 it was 1.2 to 1.5 m when the crop was established. Under DELC water table was almost dry in both seasons and this gave a negative impact on yields. The top soil was dry and crop could not establish in both seasons.

Soil data analysis from the two sites

Soil samples from two sites under study were taken and analysed. Results are shown in Table 1. Soil texture showed that there were significant differences in clay

Table 2. Effect of different types and combinations of fertilizers on yield and yield components of wheat under BR/BF scheme.

Treatments	Winter 2005			Winter 2006		
	Days to 50% flowering	1000 seed wt.	Yield kg/ha	Days to 50% flowering	1000 seed wt.	Yield kg/ha
No fertilizer (Control)	67.3^{bc}	31.3^{b}	444.69^{e}	67^{b}	31.7^{d}	632^{d}
250kg/ha D at planting	67.7^{abc}	32.3^{ab}	923.95^{cd}	68^{ab}	32.7^{cd}	1243^{c}
250kg/ha Comp. D + 52.5kg/ha N as A.N at planting.	67.3^{bc}	31.7^{b}	957.34^{bcd}	68^{ab}	33.3^{c}	1325^{c}
500kg/ha Comp. D + 105kg/ha N at planting as A.N.	68.0^{abc}	35.0^{a}	1416.35^{a}	69^{a}	35.3^{b}	1718^{b}
350kg/ha Comp. X at planting.	67.7^{abc}	34.0^{ab}	1321.62^{ab}	67^{b}	36.7^{a}	2405^{a}
700kg/ha Comp. X at planting (control)	68.7^{ab}	35.0^{a}	1254.46^{abc}	69^{a}	35.7^{ab}	2247^{a}
500kg/ha Comp. D + 35 kg/ha N at planting as A.N.	69.0^{a}	32.0^{ab}	1353.01^{a}	69^{a}	36.0^{ab}	2357^{a}
140kg/ha N at planting (as A.N)	68.7^{ab}	32.0^{ab}	628.05^{de}	69^{a}	35.0^{b}	1645^{b}
500kg/ha Comp. D at planting	68.0^{abc}	34.0^{ab}	923.86^{cd}	69^{a}	35.3^{b}	2428^{a}
Means	68.0	33.0	1024.8	68.3	34.6	1778
S.E.	0.452	0.921	119.94	0.761	0.75	117
LSD 0.05	1.357	2.736	354.87	1.32	1.3	202.6
C.V	1.17	4.82	20.42	1.1	2.2	6.6

*Figures that are separated by the same letter do not have any significant differences.

content levels with 5 and 8% in DELC and BR/BF system respectively. Silt content between the two sites also showed significant differences with 13 and 2% in DELC and BR/BF respectively. Sand content showed significant differences with 90 and 82% in BR/BF and DELC respectively. Organic matter content did not show any significant differences from each other with 0.25 and 0.3 in BR/BF and DELC respectively. Soil pH showed significantly different values statistically between sites with 4.16 and 4.7 in BR/BF and DELC system respectively. BR/BF was more acidic compared to DELC system. Nitrogen content did not show any significant difference between sites. Phosphate showed significant differences between systems with 25.8 and 7.2 ppm in BR/BF and DELC respectively. Potash was also significantly higher in BR/BF system as compared to DELC with 0.11 and 0.06 m.e % respectively. Calcium showed no significant differences between sites with 0.64 and 0.762 m.e % with BR/BF and DELC respectively. Magnesium and Sodium showed significant differences between sites with 0.18 and 0.60 and 0.07 and 0.12 m.e % respectively.

Days to 50% flowering

The control gave significant shorter number of days ($p<0.050$) to 50% flowering in both seasons compared to 500 D + 35N Table 2. All the other treatments did not show any significant differences in both seasons in the first season. In the second season control treatment and 350 kg/ha Cmp X did not show any significant differences

1000 seed weight (g)

There were significant differences ($p<0.05$) among treatments in 1000 seed weight in both seasons. Zero fertility and applying 250 kg/ha Cmp D with 52.5 kg/ha N at planting had significantly lighter seed weight (Table 1) as compared to 500 kg/ha Cmp D with 105 kg/ha N at planting and 700 kg/ha Cmp X in both seasons. Heavier seed were observed in the second season as compared to the first season. Applying 350 kg/ha X showed significant heavier seed as compared to zero 140 kg/ha N at planting.

Grain yield (Kg/ha)

Analysis of variance showed that application of nitrogen resulted in sharp increases in harvested grain yield in both seasons. Significant yield differences existed among treatments with zero fertility, 250 kg/ha Cmp D, and 250 kg/ha Cmp D with 52.5 Kg/ha N and 140 kg/ha N at planting showing significantly lower yields as compared to applying 500 kg/ha Cmp D with 105.5 kg/ha N and 500 kg/ha Cmp D with 35.5 kg/ha N at planting (Table 2). There were no significant yield differences in applying Cmp X at 700, 350 and applying 500 kg/ha Cmp D with

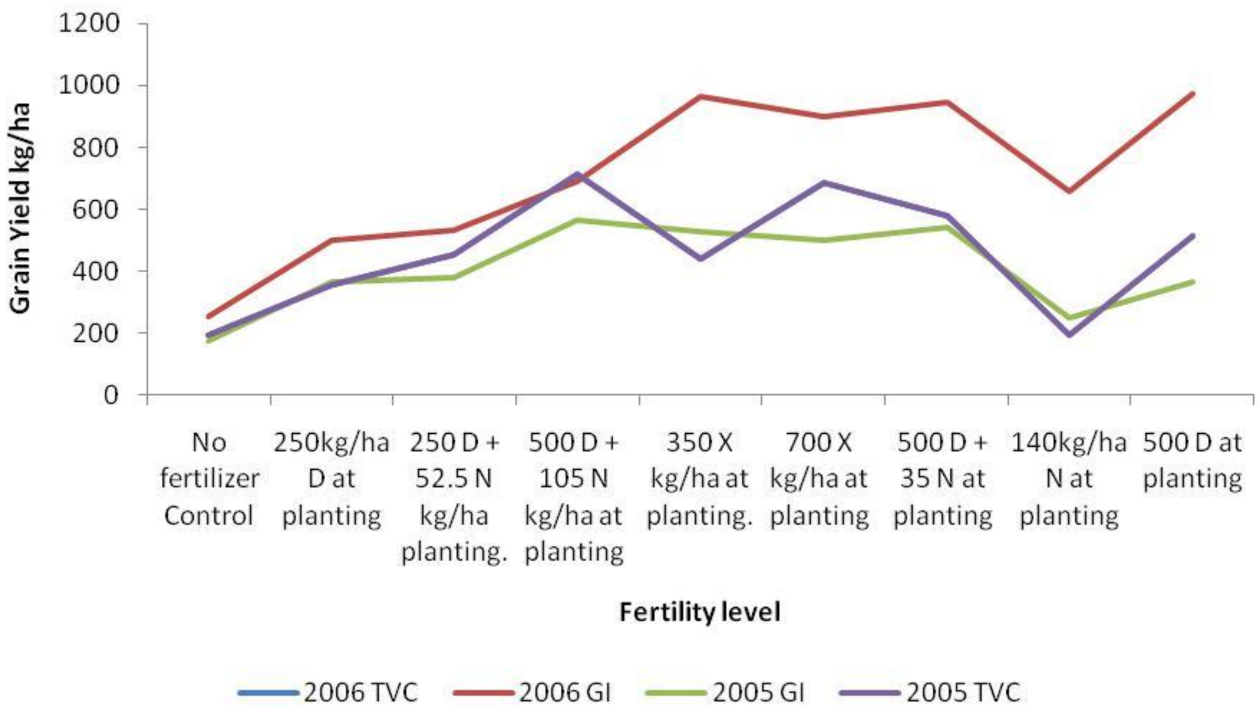

Figure 3. Comparison of gross income to variable costs of wheat grown under Broad ridge and broad furrow tillage system of cultivation.

105.5, 500 kg/ha Cmp D with 35 kg/ha N at planting. There were no significant yield differences between 500 kg/ha Cmp D, 140 kg/ha N at planting, 250 kg/ha Cmp D with half nitrogen requirement and 250 kg/ha Cmp D at planting.

Economic analysis

Highest gross margins were shown when applying 350 kg/ha Cmp X at planting (Figure 3) with $89.65 and $523.00 in the first and second year respectively. This gave $0.20 and $1.19 per dollar invested in first and second year respectively. Applying 140 kg/ha N as basal had lowest gross margin realised in the first year when moisture was limiting. Application of high basal rates showed negative gross margins in the first season. However, when soil moisture availability increased due to the preceding good rain season gross margins were positive. Applying 500 kg/ha comp D with 105 kg/ha N gave negative gross margins in both seasons.

Applying 500 and 105 kg/ha N at planting gave the highest gross income in 2005 but its variable costs are too high for a profit. By reducing the nitrogen applied to 70 kg/ha N the loss margin decreased. Applying Cmp X at 350 kg/ha gave the best in the conditions of the trial. It has the highest returns to the money invested in its production; it maximized profit and output and minimized costs.

DISCUSSION

Days to 50% flowering and1000 seed weight

Days to 50% flowering were significantly increased by application of nitrogen fertilizer (Samad et al., 2005). Seed weight increased significantly with amount of basal Cmp applied at constant moisture supply. The increase could be the nitrogen dose which influenced an increase in the grain weight. Hussain et al. (2005).

The results also agreed with the findings of Chaudhary and Mehmood (1998) who reported that 1000 grain weight of wheat was significantly affected by different nitrogen levels. This was also due to the effects of phosphate supplied by Cmp fertilizer that helped capture of mineral nitrogen in soil due to increased root growth (Giller et al., 1997). In treatments where more nitrogen was applied at planting (700 kg/ha X; 500 kg/ha D + 105N; 500 kg/ha D + 35 kg/ha N and 500 kg/haD) the seed density did not show any differences with 350 kg/ha X.

This was caused by increasing soil moisture depletion which might have influenced less nitrogen uptake. This result agreed with Ahmadi and Baker (2001); Mirbahar et al. (2009) and Johari-Pireivatlou (2010) who found that moisture stress decreased the one thousand seed weight of wheat. Grain weight is, however, reduced (Hochman, 1982; Kobata et al., 1992) due to a shortening of the grain filling period resulting from accelerated senescence.

Grain yield kg/ha

Analysis of variance showed that application of nitrogen resulted in sharp increases in harvested grain yield in both seasons. Grain yield increased as amount of nitrogen was increased from the control level to 140 kg/ha. But the soil nitrogen level was very low, due to the experimental site located in the arid region of the country where organic matter level is low (16 to 27 ppm). The results presented revealed that high nitrogen application significantly increased the grain yield over that of the control. The crop under zero fertility was nutrient stressed and flowered earlier causing hastened grain filling resulting in poor yields. Stewart (2008) found that shortages of N cause reduced tillering, reduction in head size and poor grain fill. On the other hand, Ellen and Spiertz (1980) showed that increase in grain yield from applied nitrogen was not due to an increase in seed weight, but to the seed number per unit area. Wheat grain yield resulting from application of 70 to 140 kg/ha nitrogen differing insignificantly from each other could be attributed to the low soil organic matter content (Hussain et al., 2005). He also found that wheat grain yield resulting from nitrogen application at 200 kg/ha did not differ significantly from the yield resulting from half application of nitrogen. This is evidenced by Applying Cmp X at 350 kg/ha (70 kg/ha N) giving highest yields. This could be attributed to the right amount of nitrogen which was slowly released from the Cmp form availing it to the crop most of its growing period as compared to applying ammonium nitrate as basal. Nitrogen is fused in Cmp form and acted in a slow release mechanism. High yields associated with 350 kg/ha Cmp X might also be attributed to adequate P supplied by Cmp X. Stewart (2008) also found that adequate P increases N recovery and use efficiency. Applying Cmp X up to 700 kg/ha will not increase the yield significantly because it will have reached the point of maximum return and also that moisture could be limiting. Several studies have shown the importance of optimum soil moisture in wheat production. Robinson et al. (1999) used a crop model and historical climate records (1960-1993) to produce a long-term record of yield to N fertilizers. The study proved that fertilizer N application was most profitable when available soil moisture measurements before sowing was above average. Nitrogen can be applied at high rate of 200 kg N/ha Hussain et al. (2005) to any wheat variety without having adverse effect on the recommended yield but moisture must be available. These results agree with the findings of Bakhsh et al. (1999) who reported that by increasing the level of nitrogen, the grain yield was also increased. However, with residual soil moisture the optimum fertilizer levels are found to be lower for the farmers to realise profit margins that are high compared to an irrigated crop.

Nitrogen use efficiency was highest on 350 kg/ha Cmp X; 500 kg/ha Cmp D with 35 N and 500 kg/ha Cmp D showing 18.9, 19 and 26 kg/ha grain per kg of nitrogen applied in first year and 34.4, 33.7 and 69.4 kg/ha in the second year respectively. This showed that when there is more available water in the soil crop benefits more from fertilization. Applying more nitrogen at 700 kg/ha Cmp X reduced nitrogen use efficiency to 8.95 kg/ha grain per kg of applied nitrogen almost half that of 350 kg/ha X. As the nitrogen use efficiency is reduced yield is also reduced giving no benefit to the farmer. Water stress has been shown in many occasions to reduce N uptake and consequently N fertilizer use efficiency (Rego, 1988). Hoogenboom et al. (1994). noted that the processes affected by water stress include vegetative development, reproductive development, photosynthesis, biomass partitioning, grain, ear or head addition, leaf area growth and expansion, root growth, transpiration, senescence and various other processes. Water deficit close to anthesis accelerates development (Simane *et al*., 1993); the accumulation of soluble carbohydrates in the stem occurring between anthesis and the linear phase of grain growth is decreased (Nicholas and Turner, 1993).

Conclusion

When farmers endeavour into crop production they focus on profitability. Applying 350 kg/ha gave the highest gross income in both seasons. This was the best option from the treatments tested when growing wheat in vleis under the BR/BF tillage system in Natural Region 4 because it had the highest returns to the money invested in its production. It maximized profit, output and minimized costs. Very high rates failed to give best returns under BR/BF system. The DELC system failed to sustain a crop in both seasons. Therefore the BR/BF system showed the best results in terms of gross margins, return per dollar of variable cost and grain yield of wheat.

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